University of Tennessee, Knoxville

TRACE: Tennessee Research and Creative Exchange

Chancellor’s Honors Program Projects

Supervised Undergraduate Student Research and Creative Work

5-2018

UT Football Automated Practice Target

Mary Elizabeth Iannuzzi
miannuzz@vols.utk.edu

LEe Fullam
lfullam@vols.utk.edu

LIndsay Little
llittl14@vols.utk.edu

Julia Meyer
jmeyer14@vols.utk.edu

ME 460 Senior Design Report

UT Football

Automated Practice Target

Julia Meyer
Lee Fullam
Lindsay Little
MaryBeth Iannuzzi

Steven Foster
University of Tennessee
Tickle College of Engineering
Knoxville, TN

Abstract

The University of Tennessee football team, along with any other football team, benefits from a diverse practice routine. Our focus was on the quarterback, by creating a machine that he could easily use to practice his passes for various routines. Our design includes a moving target programmed so that the user is able to determine what play he would like to practice with a control panel, and continuously make passes to this target which simulates the movement of his receiver. The design incorporates a pulley system run by a motor that changes the position, velocity, and acceleration of the target from left to right, along with an easy to use instruction manual and control panel. The machine will make quarterback passing practice easier, more accurate, and more effective.

I. Project Background

A) *Problem Statement*

The original problem statement was given as: "In order to maintain good passing techniques and results, quarterbacks need to practice passing to moving receivers. To achieve this without requiring a squad of receivers around, quarterbacks practice their passing using carts which have targets attached to and are physically pushed by program personnel." Last year's group already created a design and manufactured many of the parts, so our task was to improve upon this design. Improvements have been completed by recalculating, troubleshooting, and finishing the design. In addition to the completion of the mechanical structure of the system, a touch screen user-interface has been implemented for the control of the system.

B) *Last Year's Design*

The design that the previous mechanical engineering senior design group came up with is shown below in Figure 1. In this design, a static base sits on the left, which houses an idle pulley and the base. A driven base is on the right side of the figure, which houses the motor and motor controls. The target is shown in the middle with a counterweight attached and a spring on the right side. The figure is not to scale as the distance between the two bases is meant to be approximately 15 yards. The bases were also given wheels for easy portability.

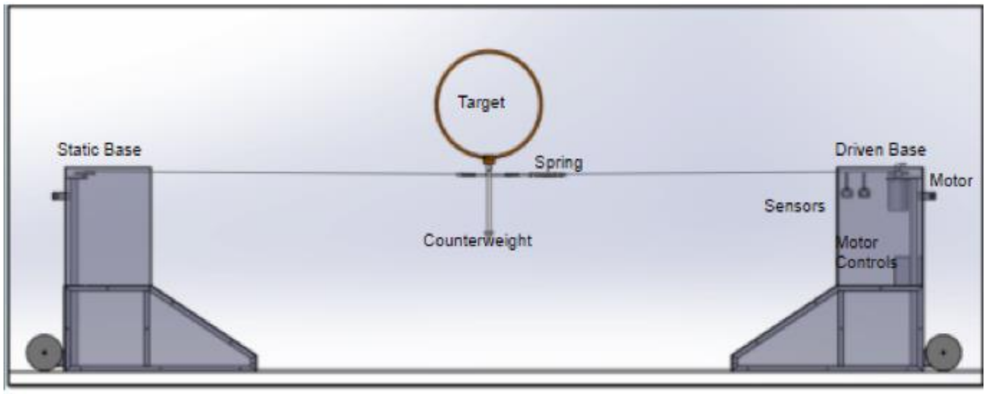


Figure 1: Last Year's Design

II. Approach and Design

A) <u>Initial Testing and Usable Parts</u>

Our initial tests of last year's design were very telling. The mechanism worked in general, as the motor was functional and able to move the target from left to right. Although, this was about the only thing we had to go off of, considering the tensioning system was not backed by any design calculations, the pulley system was very unstable and unreliable, and there was no interface allowing a non-engineer user to operate the machine. Fixing these issues would each take their own new design processes with many iterations, particularly with our tensioning system. One of the designs that we were able to keep from the old design was that of the two bases, shown in Figure 2.

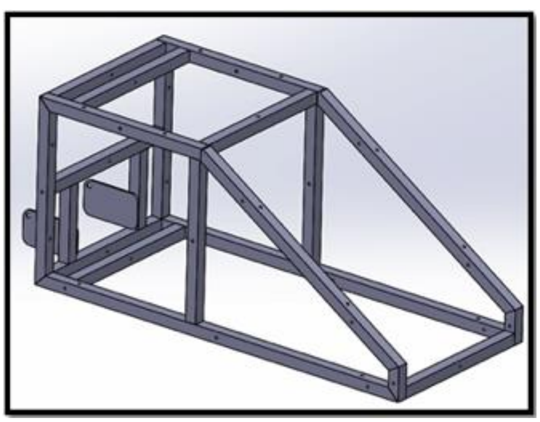


Figure 2: Base Frame

We were also able to keep the pulleys provided by the previous group, shown in Figure 3. These pulleys are V belt pulleys made of Zamak, which is a zinc alloy. On the driven side of the mechanism, this pulley was modified to attach the encoder and to connect it to the motor. This modification was redesigned. On the static side, a low friction bushing is used so the pulley can rotate freely on a shaft.

Figure 3: V-belt Pulley

Aside from these two pieces, we've gone through the redesign process for all other mechanical components of the system.

B) ***<u>Items for Redesign</u>***

1) <u>Target</u>

One of the first things we knew we wanted to redesign after our initial tests was the design of the target. The initial design is shown in Figure 4.

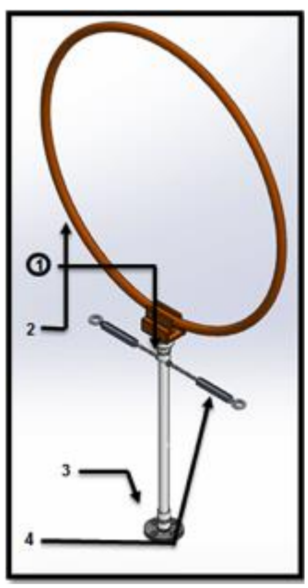


Figure 4: Initial Target Design

The previous design team described the mechanics of the assembly as such:

In this figure, number 1 points to the location of a friction union. This is a PVC joint that allows for adjustment in the angle of the target. Since the angle of the target can be adjusted, the quarterbacks can practice from many different angles and locations to simulate different routes. Number 2 points to the hoop. This is made of high density polyethylene. This is a lightweight plastic yet is strong in case of potential impact. It does not deform in sunlight so it is safe for continued use outside. The diameter is 2.5 feet to simulate the area of the wide receiver that is ideal for him to catch the ball being passed. Number 3 points to the counterweight which is made of a combination of steel and PVC. This lowers the center of mass so the target can be hit and return to the correct location. The pieces of the counterweight are cemented together to keep it from falling apart. Number 4 points to the location of a turnbuckle. The turnbuckle is made of aluminum which makes it lightweight. The turnbuckle is connected to a threaded rod. This system allows for the line to be tightened and adjusted to account for differences in distance and tension. The length of the rod also helps counteract the target from twisting as it is moving.

We understood the intentions behind this design, but the calculations left out some key factors. The target assembly was very heavy, making the rope sag. The significant sag in the rope caused by the weight of the original design caused a change in vertical position as the target moved horizontally. The target was also higher than an average receiver's chest when it wasn't at the lowest point of sag. These were the reasons we decided to completely redesign this part. Our design was a flat, plastic, circular target. Specifications for the redesign are shown later in the report.

2) <u>Idle Pulley Shaft</u>

Another element we needed to redesign was the idle pulley shaft. During the first test run of the target, the idle pulley flew off the shaft. This incident occurred because the shaft did not secure the pulley in place vertically. Figure 5 shows a picture of the original design and the unsecured pulley. This was a safety concern and needed to be secured. Also, the shaft was attached to the base with one small screw (Shown in Figure 6). That shaft mounting design showed signs of weakness, so this was another problem that needed a solution.

Figure 5: Shows the top of the original idle pulley shaft.

Figure 6: Shows the bottom of the original idle pulley shaft.

3) Encoder Mount

We also redesigned the mount for the encoder because the old design, shown in Figure 7 below, allowed the encoder mounting plate to move and rub on the motor axis. The encoder is used to inform the computer about the position of the target based on rotation of the motor, so it is important that this system be secure. The mounting plate was also bent and made the encoder difficult to align with the axis. The new design is secure and allows no movement or deflection. It also allows an easy one-way fit assembly.

Figure 7: Current encoder mounting assembly.

4) Position Sensor

A positioning sensor is needed in collaboration with the encoder to allow the computer to know when to stop the run, where the target it, and which way to move to reset the target automatically. The original sensor was an infrared sensor which required the disturbance of a beam of light in order to be triggered. We also decided that a proximity sensor would better perform the task of stopping the pulley at an appropriate time.

5) Rope Tension and Tension Verification

This system works by quickly moving a rope around a set of horizontal pulleys which means gravity does not naturally aid in the tensioning of the system. Because of this, it is imperative that there is enough tension in the rope such that there will not be slip between the rope and pulley when the motor is in operation. The previous group calculated the necessary tension for zero slip to be 90 lb and designed a system of ensuring that this tension was met. In addition to re-calculating the required tension, we also needed to clarify the design of the tensioning system. Although the design was outlined in general by the previous group, it needed to be calculated specifically to fit all of the parts included in our system design.

6) Electrical Cabinet

A place for the electrical cabinet to be mounted in order to securely hold all of the electrical equipment in an orderly fashion had to be designed, as well as a few other minor things that will be discussed throughout the report.

7) Base Friction

The bases slipped when the machine was tested because the tension in the rope was larger than the holding force of the bases. A person was needed to hold each base back during the testing to keep the tension. The bases need to be modified so that the friction force can withstand the tension force of the rope.

C) Design Selection Process

After we recognized the problems and improvements we wanted to work on, the next challenge was selecting a specific design for each problem. Since there was four mechanical group members, we usually had four different approaches to a design. This created some challenges, but in the end it made our designs stronger. We used a technique that Mr. Foster, our project mentor, showed us. We called it a decision matrix, which is shown in Table 1. Table 1 shows an example of two designs for a tensioning system. Each design is given points based on specified criteria. Some of the criteria is weighted more than others. After each design has been given points for each criteria, the design with the most points is the selected design. In this example,the designs were a tie so we consulted Mr. Foster for advice, and we ended up using the original tensioning system design as advised. The criteria can change depending on the specific problem, but this decision matrix technique was our process in eliminating and selecting the designs in Section II.D.

Table 1: Decision matrix for the tensioning system design selection.

	Crank	Torsion Spring	Datum (Manual Pull)
Functionality	.5	.5	0
User Friendliness	1	0	0
Reliability	.5	.5	1
Assembly	0	1	1
Safety	0	1	0
Tension Precision	1	0	0
Total	3	3	2

D) ***Design Improvement and Redesign***

1) Target

As previously stated, we decided to redesign the target in a way that caused less sag, occupied less vertical space, and moved at a height that is more compatible with the height of the average receiver's chest. The design chosen was a series of concentric hoops made of plastic connected by a central horizontal strip. A small counterweight sits at the bottom of the hoop. The rope weaves through holes drilled in the central plastic strip so that tension remains in the rope and does not pull horizontally on the target. This effectively holds the target up while eliminating the extra weight that connection links would add. We calculated the necessary dimensions of the hoop design, including material thickness and hoop diameter, by analyzing the tension forces on the hoop. The hoop and its counterweight are shown in Figure 8.

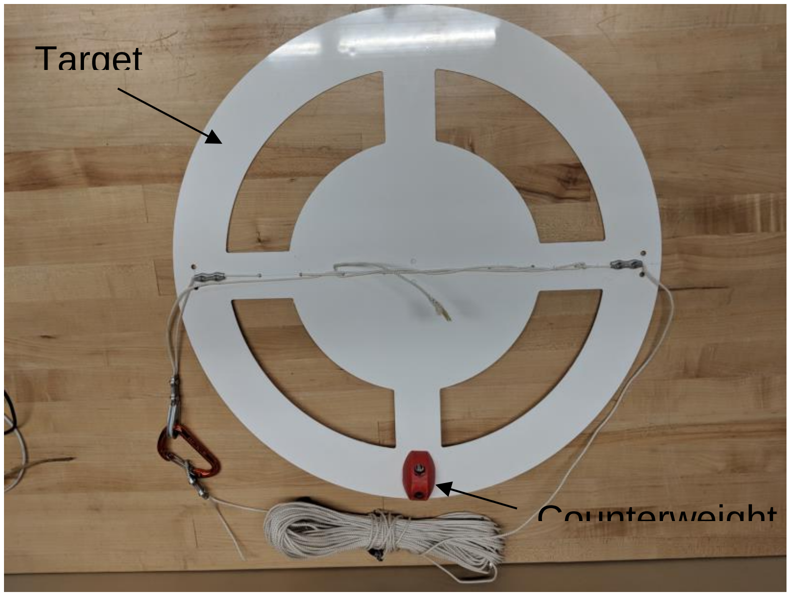


Figure 8: Target Hoop Design

2) Idle Pulley Shaft

The new shaft design (Shown in Figure 9) was created from stainless steel 304. This was chosen because it is a hard alloy and will not corrode. It is also a similar material from the original design, which worked well. The new design includes a C-clip directly above the pulley to prevent the pulley from sliding up. This is shown in Figure 10. The shaft resembles a shoulder bolt where the bottom of the shaft is threaded. It goes through the base plate and can be tightened with a half inch nut underneath the plate. This creates a more secure mounting connection. The shoulder section of the shaft has two flat parallel cuts where a wrench can fit. This ensures that the nut and shaft can be tightened properly. The previous design did not have this, which made it difficult to tighten the shaft to the base. By having the wrench cutout, this also ensures that the shaft will not be damaged or cause unwanted friction from material deformation. Overall, the new shaft design properly secures the pulley to the shaft and the shaft to the base.

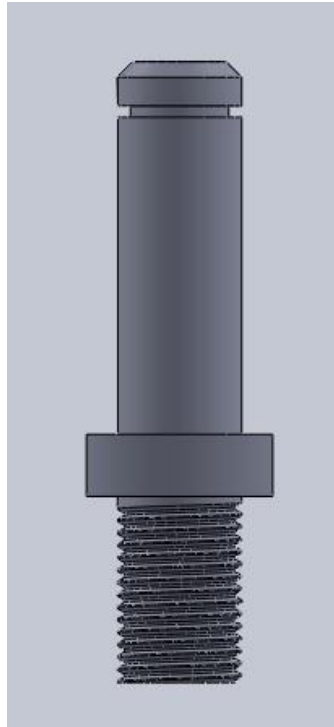


Figure 9: Shows the new stainless steel 304 idle pulley shaft design.

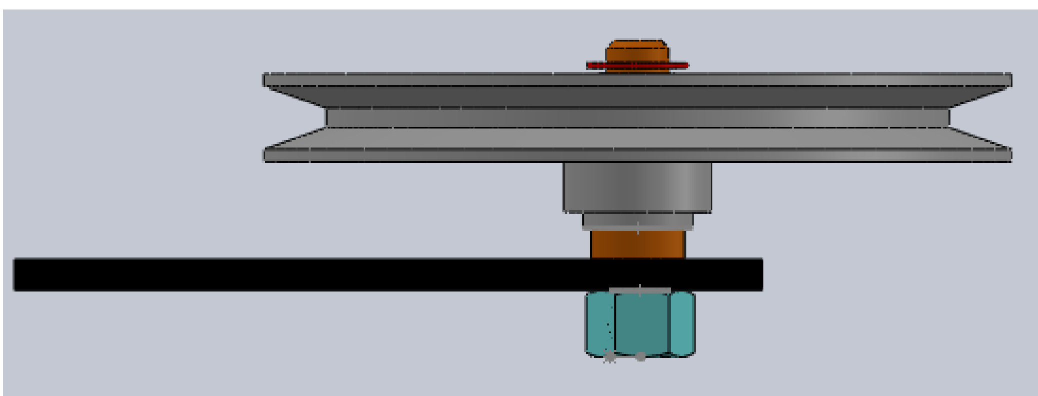


Figure 10: Shows the new idle pulley shaft mounted to the base with the pulley attached.

3) Encoder Mount

The previous encoder mounting assembly was done by last year's team as a last-minute effort to attach the encoder. A steel pipe was used to mount the plate that the encoder would attach to. The pipe was too tall which forced the plate to bend in order to be able to attach the encoder to the motor. The deflection of the plate plus the movement from the pipe not being secure caused it to interfere with the motor's axis. We redesigned the mounting assembly to fix these issues. As shown in Figure 11 below, the new design consists of two main parts: the encoder mounting plate and the mounting plate base.

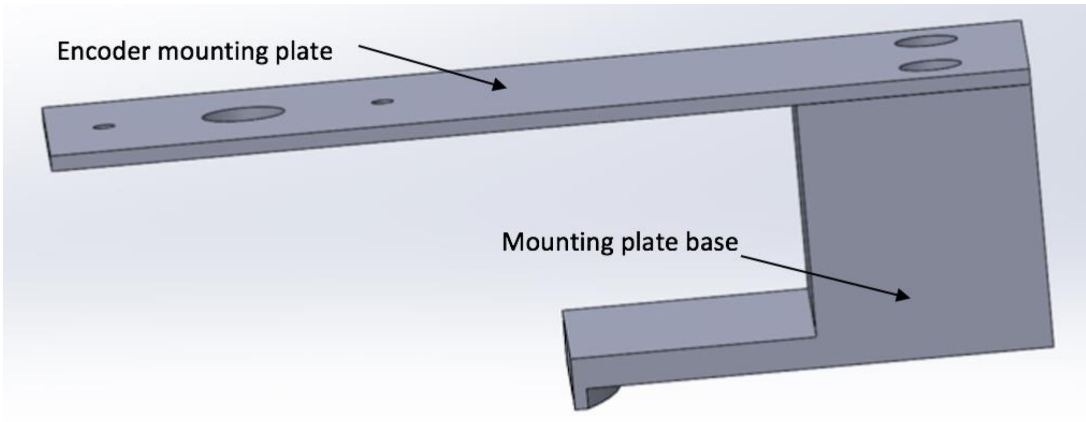


Figure 11: New encoder mounting assembly.

For the new encoder mounting plate, another hole was added beside the one that the bolt goes through and the excess length from the back was removed. Instead of a steel pipe for the base, it was changed into more of a solid block and made of aluminum with two holes drilled in it. Bolts were inserted into the holes to hold the assembly down to the motor mounting plate and prevent movement between the parts. There is also a ledge that extends out from the bottom of the base which consists of a small overhang at its end. The overhang has the same radius as the hole in the motor mounting plate so it can fit closely to the edge, shown in Figure 12, and aid in alignment and preventing movement.

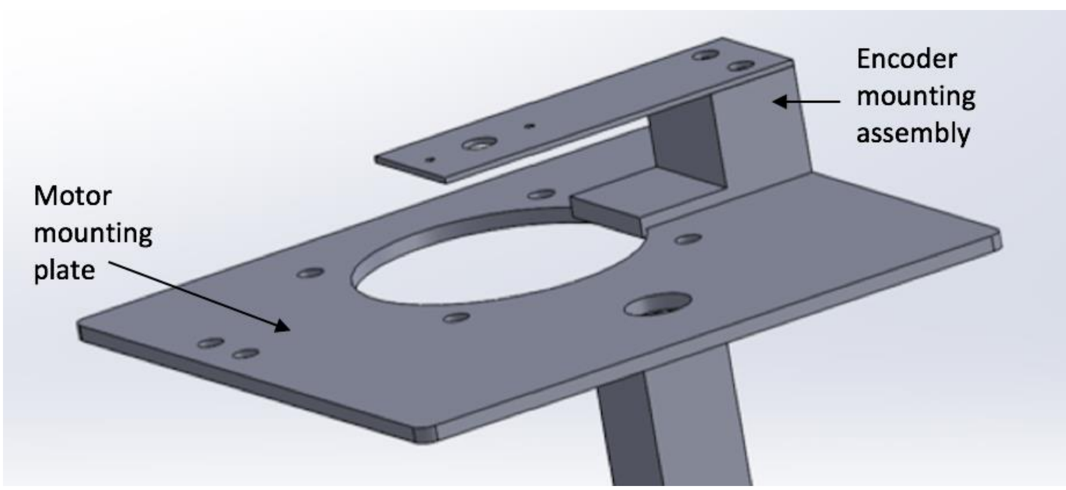


Figure 12: Encoder mounting assembly attached to motor mounting plate

4) Sensor

The sensor that was chosen by the group before us was an infrared sensor, pictured below.

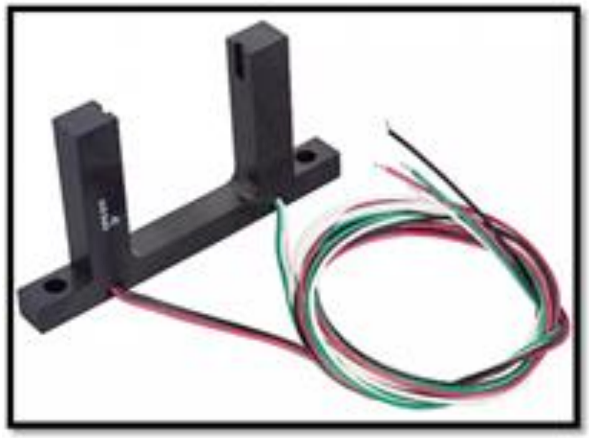


Figure 13: Infrared Sensor

We decided that, though simple in operation, this sensor would not be the most reliable way to collect the data we needed on the location of the target. The purpose of the sensor is to alert the system that the target is approaching the end of its run. This information is processed in the code and stops the rotation of the driving pulley. An infrared sensor works on a binary system, indicating if the receiver does or does not see light. This would mean that there had to be some variation of light through the middle of the sensor. Because it would be impractical and unreliable to try to create a path of light within the rope (for example, making a section of the rope transparent), the only other option is to attach some sort of "flag" of extra material to the rope. This flag would need to pass directly through the infrared sensor in order to initiate the motor stopping. This would be a problematic design because the flag would not consistently line up with the sensor on its own. This means that in addition to the sensor, a separate structure would have to be built to direct the flag to the appropriate position as it moved through the sensor. This process overall, in addition to adding unnecessary bulky hardware to the design, would leave more room for error in the sensing process. It was decided instead to use an inductive proximity sensor, specifically the Automation Direct PTW-AP-2H pictured below.

Figure 14: Automation Direct PTW-AP-2H Inductive Proximity Sensor

An inductive proximity sensor works by detecting metal that is in front of or approaching the sensor. This means that the “flag” only needs to come into proximity of the sensor rather than aligning in a very specific direction to block a beam of light. The “flag” which triggers the sensor is flexible steel wire that is wrapped around the rope longitudinally. Inductive proximity sensors are more effective for certain metals than others. We chose this particular sensor because the sensing distance was listed as 25mm which is relatively high for this product. We chose steel wire because this sensor has a sensing factor of 1.0 for steel, meaning it can sense to the full distance. The wire is flexible enough that it does not interfere with the functionality of the rope as it passes around the pulley, but large enough to trigger the proximity sensor. The sensor is placed far enough away from the pulley that the metal pulley and base will not interfere with the sensor, but close enough that the pulley will naturally guide the rope along a reliable path, unaffected by bounce. The sensor can face any direction as long as it faces directly toward the rope but was designed to ease the wiring process and avoid unnecessary lengths of wire to connect the sensor to the electronics box. The sensor is mounted to the base plate of the motorized pulley as shown below:

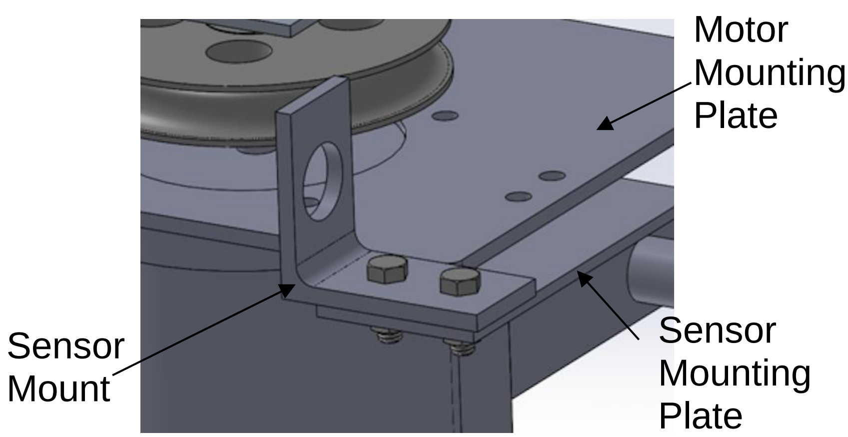


Figure 15: Sensor Mounting Assembly

5) Tensioning System

It was decided that the initial tensioning system suggested by the previous group was a reliable and effective design. Instead of redesigning the tensioning system, we decided to improve and fully develop the previous design. A basic schematic of the original design is shown below.

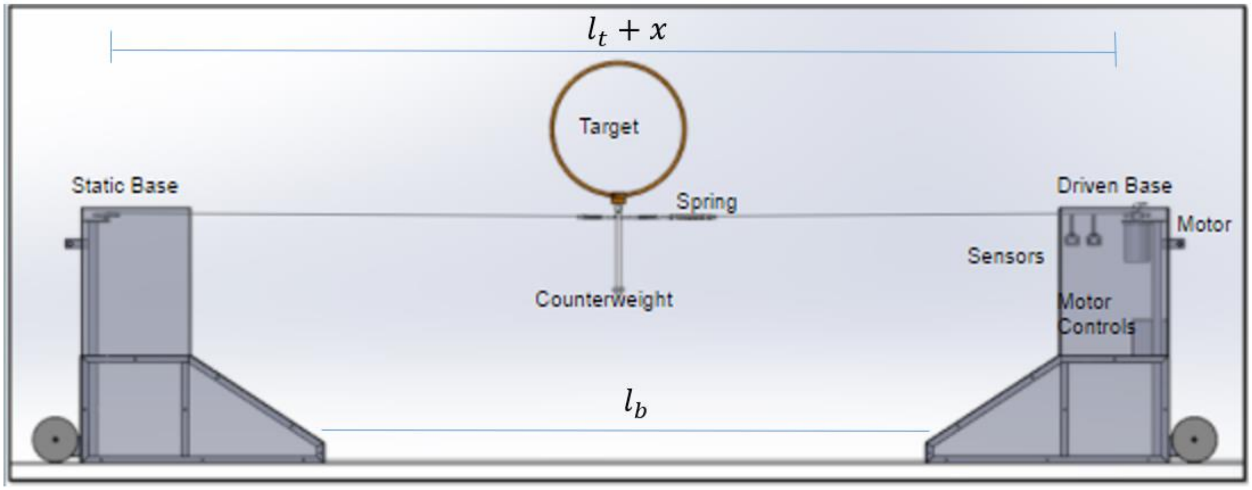


Figure 16: Side view of system (lateral rope length significantly compressed)

The above figure shows a spring connected to the target and the rope that is attached to the pulleys. At the bottom of the system, a separate cable is attached to both of the bases and is rigid. The length of this rigid cable is such that it will be taut when the spring is at an acceptable tension for the pulley system to run properly. The length of the rope from one pulley to another, l_t, includes the spring under zero tension. The fully tensioned length of the rope with the springs stretched is equal to:

$$full\ length = l_t + x = l_t + \frac{F_t}{K} \quad [1]$$

Where F_t is the full tension force and K is the spring constant. The stretched distance of the spring derived with this equation is denoted x. The final design of this tensioning system relates the length of rope needed compared to the length of the tensioning table. This relationship is defined in equation [2] below:

$$L_r = 2\left(\frac{C}{2}\right) + 2\left(L_{tc} - 2\left(\frac{2}{12}\right)\right) - (T_s - 18)(K) - L_s - 2(H) \pm 1.95 \quad [2]$$

Where L_r = rope length, L_{tc}= length of tensioning cable, T_s= tension in the spring, L_s= free length of spring, H= carabiner clip hoop length.

The tolerances of the system are a result of the manufacturing tolerances of each individual piece involved in the equation, where the pulley, carabiner connectors and loops on the ends of the tensioning cable are each true to design +/- 0.05 inches. The tolerance for added length based on weaving the rope through the target was taken conservatively to be +/- 0.3 inches. The spring has the largest contribution to the tolerance with a 10% tolerance in extended length. In the case of the spring being stretched to the expected 13.9 inches, this would be a tolerance of 1.4 inches when rounded. The tolerance must be accounted for when ensuring the accuracy of the tensioning device. Because it is a minimum tension that must be attained in order to eliminate slip, the system should be over tensioned by the tolerance distance to ensure that the rope is in the required tension at all time. The tensioning cable at the bottom of the bases is attached with eye loops with threaded screws and a bolt. The screws are longer than necessary to fit through the metal base which allows for adjustment of up to an inch on each side. The tolerance can therefore be adjusted for by setting up the length of rope and tensioning cable as calculated with equation [2] and then attaching each eye loop at full length out from the beam, adding length to the tensioning cable and therefore adding tension to the rope.

6) Tensioning Spring

The tensioning system design requires a spring of known K value, initial tension, length, and maximum force. The spring selected by the previous year's senior design team did not meet the design specifications of the system and would have deformed well before the necessary tension in the rope was achieved. A new spring was selected such that the maximum force that the spring was capable of withstanding was greater than 90 lb. In addition to the strength of the spring, it also needed to have a relatively low K value. This is a necessary design factor because the lower the K value, the easier it is for the user to be within an acceptable range of tension based on stretched spring length. This is because a greater stretch will pertain to a lesser change in force when compared to a spring with a higher K value. We chose the T33350 looped end spring from Associated Spring RAYMOND with a free length of 7.95 inches, an initial tension of 18.43 lb, a K value of 12 lb/in, and a maximum force of 122 lb. This spring is pictured below:

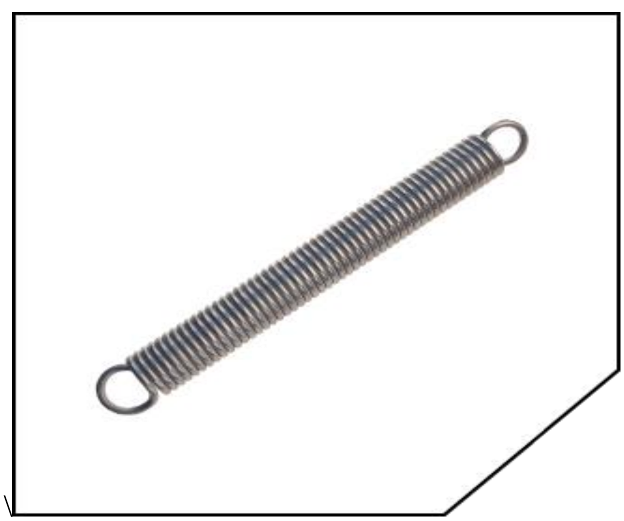


Figure 17: T33350 Associated Spring RAYMOND extension spring

This spring under the 90 lb calculated tension would be stretched to a length of 13.9 inches. The tolerance of the spring stretch is +/-10%. In practice, the spring was found to have an initial tension closer to 16 lb. This would mean that it would actually need to be stretched closer to 14.1 inches total length to achieve 90 lb of tension. This was very difficult to achieve by manually pulling the bases backward, and in practice, the system was run below 90 lb of tension. It was found through empirical testing that at 65 lb of tension the system ran smoothly and without slip and then encoder was able to effectively keep location information on the target.

7) Electrical Cabinet

The electrical cabinet is mounted to the base near the motor. It is mounted with bolts straight through the side of the box which attach to the central vertical pole of base. Figure 18 shows the electrical cabinet mounted on the frame. This location is in a convenient place and a good elevation for user access. The electrical cabinet will also need a hole drilled in the bottom for wire access. A rubber grommet (shown in figure 19) will be placed along the inside rim of the hole. This prevents the cables from being frayed or broken because the thin metal can be sharp.

Figure 18: Shows the electrical cabinet in the position it is mounted to the motor side frame.

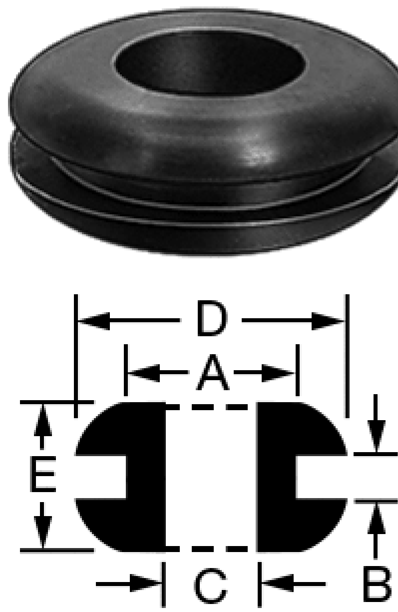


Figure 19: Shows a picture of the type of rubber grommet that will be used.

8) Friction Strips

The machined metal based proved problematic as it would slip across the floor under tension. To fix this problem, rubber strips were added to the bottom of the base which provided a higher coefficient of friction and helped keep the base from slipping while in use. These strips are shown below in figure 19.

Figure 19: Shows the rubber added to each base to keep them from slipping.

The friction strips were successful in keeping the base from slipping on the outdoor surfaces they were tested on, but some slip was still seen at full tension when on smooth painted or glossy floors. While the strips prevented slip, they simply transferred the problem to the front of the base and caused problems with tipping. This was addressed by placing weights or sandbags at the back of each base.

E) ***New Designs***

1) LED Strip

An LED light strip is attached to the motorized base to simulate the first part of the receiver’s route. Any length up to 50 ft can be set up as an extension to the horizontal motion run by the target. A reel allows for easy set up and take down, and cones allow for high flexibility in the shape of the route run by the lights. The chosen length of LED lights set up for each particular play can be input by the user on the touch screen.

Figure 20: Photo of LED light system

2) Kill Switch

In order to insure the safety of the user, a kill switch was needed that would mechanically stop the power to the motor in the event that the electrical sensors failed. The kill switch system works based on a limit switch and a slug placed along the rope. The rope runs freely in between two upright metal poles, but the slug is too big to fit between the poles. When the slug reaches the kill switch it catches on the poles and pushes the limit switch down, cutting power to the motor. Based on empirical testing of full-speed motor stop time, the distance to a full stop was calculated using equation [3] below.

$$\Delta x = vt - 0.5(at^2) \quad [3]$$

Based on the results of this calculation, it takes the motor 3.13 ft of rope to come to a complete stop. The slug is placed 4 feet away from the end of the spring so that there is enough stopping distance in between the activation of the kill switch and the target reaching either pulley. The system is pictured below:

Figure 21: Photo of kill switch

3) Programming

The football team generously provided data from multiple receivers which allowed the computer science team to program the system to run at speeds specific to UT receivers.

The work done by the computer science team was essential to the automation of the system and allows users to run the play repeatedly using a touch screen.

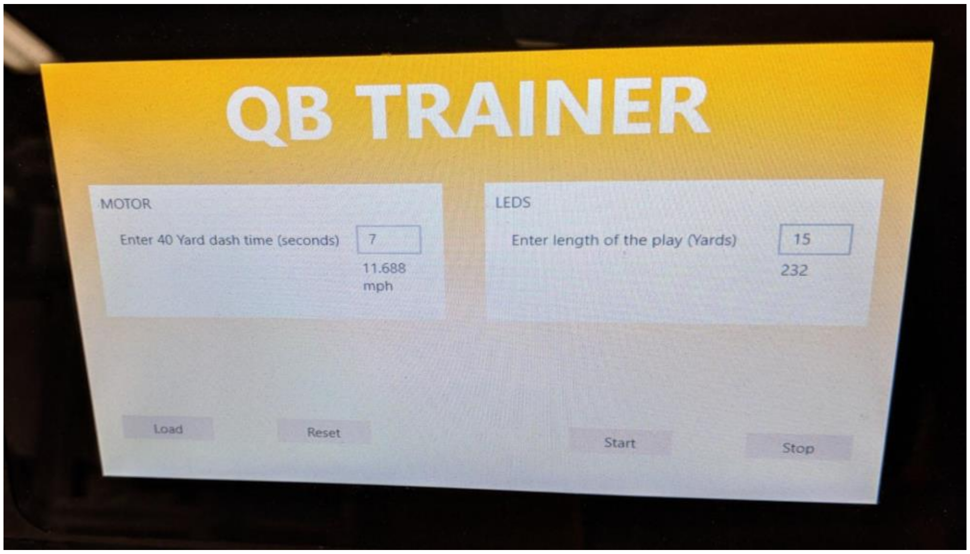


Figure 22: Photo of touchscreen user interface

IV. <u>Further Improvements</u>

1) Base Weight System

Once the slipping problem was addressed with the rubber bases, we began to encounter problems with tipping while putting the system into tension. We solved this by stacking weights and sandbags on the back of the bases. This would need to be improved to a more user-friendly system before the project was given to a customer. The design we believe would be best would be to attach a set of horizontal poles to the back of each base which work like weight holders for gym equipment. This would make it easy to add, remove, and store weight, and effectively keep the bases from tipping.

2) Sag Reduction

Though the new target design causes less problems with sag than the original design, we believe that the problem should still be further addressed until it is managed to get the target as close to horizontal with the pulleys as possible. We believe one solution to this problem could be to reposition the spring from directly next to the target to the other side of the rope, opposite the target. The weight of the spring on the opposite side of the pulley would not only be negated from the target weight, but would also create and opposing force which would at to lift the target.

3) Tensioning Aid

Though the cable-based tensioning system accurately measures that the system is in proper tension, it does not provide any mechanical advantage to a user who is setting up the target system. We designed a system during the first semester which included a crank and gears to tension the rope. We believe that something like this could be added so that the user could place the bases in an appropriate position and then be able to put the rope into 90 lb of tension using a mechanical system.

V. What We Learned

1) Gantt Chart and Planning

The importance of the Gantt chart was realized toward the end of the first semester. Because we did not stringently follow our Gantt chart we did not have a great timeline of what exactly we were going to get done and when. During the second semester, we kept to stricter deadlines, but we were still small minded about perfect testing. We learned that you need to stick to your testing schedule even if every piece isn't perfect yet or you are still waiting on a part to be manufactured. As long as the majority of things are in place, progress can be made through testing those aspects of a project where as waiting for the parts to come in will only waste time. A way that we could further improve our use of the Gantt chart would be to have a more integrated chart with the computer science and electrical team. This way everyone would be on the same page about expectations and deadlines throughout the timeline of the project.

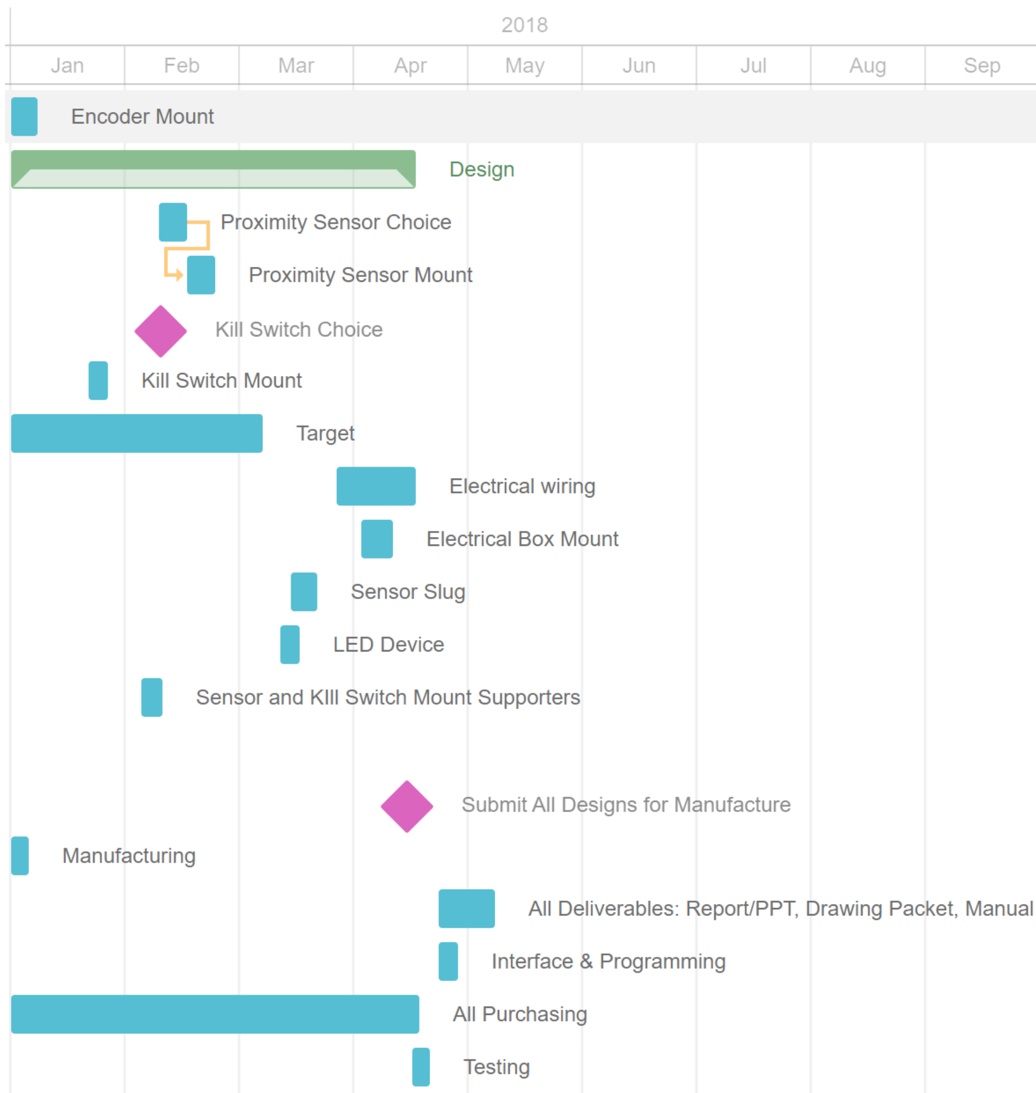
2) Buy Backup Equipment in Case of Failure or Damage

One problem that we encountered as we began to test the system more often is that many of our parts were breaking. This was a big problem with electrical pieces but also effected some mechanical pieces such as the kill switch. Because we only bought what we needed, this meant that we would get behind in our testing while waiting on new parts to arrive. This could be remedied by being very cautious of the quality and use of the parts you are buying, and, especially in situations where pieces will be subject to an unstable environment, ordering extra parts ahead of time.

3) <u>Communication Between Interdisciplinary Fields</u>

We realized during the first semester that communication with both the electrical and computer science team was going to be incredibly important as we continued to move forward with integrating the mechanical and electrical pieces. Unfortunately, we still struggled with this communication and it lead to a great amount of stress and lost time throughout the semester. In the future, we know to establish expectations of communication early on in the project and address any communication issues from the start so that they can be resolved before they start to have a larger effect on the progress of the project as a whole.

V. Appendix A: Gantt Chart



Works Cited:

Figure 14: https://images-na.ssl-images-amazon.com/images/I/61EyRU2bgaL._SY355_.jpg

Figure 17: https://www.mcmaster.com/#9307k49/=1akzra3

Figure 18: https://www.mcmaster.com/#27185t11/=1akzro7

Figures 1-4 obtained from “Moving Target Report for ME 460 Senior Design Class” by “Feels like 98” (Cameron Kerby, Tyler Rice, Josh Smith, Evan Surrett, Mary Williams).

A special thanks to Brad Roll for supplying UT receiver 40-yard dash data.